J6.4

ESTIMATES OF HORIZONTAL ADVECTION USING FIELD MEASUREMENTS IN A CROP CANOPY

John Kochendorfer*, Kyaw Tha Paw U, and Young-San Park
University of California, Davis

1. INTRODUCTION

Eddy covariance is widely used as the primary method to estimate the net exchange of a scalar between a land surface and the atmosphere. The mass conservation and the continuity equations reveal that when the surface near eddy covariance instrumentation is not homogeneous corrections for horizontal and vertical advection must also be included (Paw U et al., 2000; Baldocchi, 2003). Restraining the use of eddy covariance campaigns to ideal or even near-ideal locations is neither practical nor possible, but modeled and experimental research on the potential magnitudes of advection within canopies is scarce.

In an intensive field experiment a suite of instruments designed to measure advection and vertical fluxes of heat and water vapor was placed at varying distances from the edge of an agricultural canopy (*Sorghum bicolor*). The magnitude of measured horizontal advection of latent energy (LE) and sensible heat is large near the edge of the canopy, often greatly exceeding the magnitude of vertical fluxes. Comparison between observed results and a higher-order closure model (Park et al., 2006) of advection across a canopy edge is made.

2. METHODS

2.1 Experiment and Site Description

On the UC Davis Campbell Tract field station research staff planted a sorghum hybrid which grows to a height of 1 m. The cultivated area measured 120 m wide in the east-west direction and 180 m long from north to south. To the south of the sorghum field there was over 100 m of bare soil. The terrain is both flat and level, and prevailing winds are from the south. One sided LAI of the mature sorghum crop was 4.

Corresponding author address: John Kochenodorfer
Univ. of California, One Shields Ave., Davis, CA 95616-8627;
e-mail: jkoch@ucdavis.edu

Using four three-dimensional sonic anemometers and four infrared gas analyzers (IRGA) 10 Hz turbulence data including water vapor, wind speeds, and sonic temperature were measured at a height of 1.2 m at three different distances north of the canopy edge and at one location over the bare soil upwind of the canopy. These H_2O and CO_2 eddy covariance instrument groups were located from south to north at -10 m, 5 m, 33 m, and 143 m from the southern edge of the field. With three additional three-dimensional sonic anemometers also running at 10 Hz wind speed and temperature were measured at a height of 0.5 m within the canopy at x = 4.7 m, 33 m, and 143 m. Mean temperature and relative humidity (RH) sensors were mounted at four heights and at five different distances from the edge along the same transect as the fast-response instruments. We also measured net radiation and ground heat fluxes at the three different sites within the canopy and at the bare soil site upwind of the canopy.

2.2 Calculations

From this data half hour averages of the vertical fluxes of sensible heat were calculated within and above the canopy at the different distances from the edge and vertical fluxes of latent energy (LE) were calculated at the different locations above the canopy. Horizontal and vertical advection of heat and water vapor were also calculated at three different distances into the canopy. The horizontal advection calculations were made using horizontal gradients in temperature and vapor pressure and the measured wind speeds. Simple linear shape functions were used to create vertical wind speed and scalar profiles based on the measurements available (two heights for wind speed and four heights for the scalars of temperature and RH) and the product of the wind speed and the scalar gradients were numerically integrated from the ground up to 1.2 m. In addition to the product of the scalar gradient and the mean wind speed, the product of the horizontal gradient of wind speed and the scalar was of significant magnitude near the edge.

Horizontal advection =

$$\int_{0}^{z=1.2h_c} \overline{u} \cdot (\partial c / \partial x) \cdot dz + \int_{0}^{z=1.2h_c} \overline{c} \cdot (\partial u / \partial x) \cdot dz \qquad (1)$$

The scalar is expressed in units per m^3. Near the edge vertical advection was calculated by using the measured vertical wind speed multiplied by the vertical gradient of the scalar between the top two sensors near the anemometer.

$$\textit{Vertical advection} = \int_{z=h_c}^{z=1.2h_c} \overline{w} \cdot (\partial c / \partial z) \cdot dz \qquad (2)$$

2.2 Instrumentation

The three-dimensional sonic anemometers consisted of 6 Gill WindMaster Pros, and one Campbell Scientific CSAT3. In addition two other Campbell Scientific CSAT3s were occasionally available to use at 20 Hz in cross calibration and spectral analysis and to help fill gaps in wind profiles for validation of the shape functions used in the advection calculations. Two of the IRGAs used were closed path LiCor 6262s and the other two were LiCor 7500s. The temperature and relative humidity sensors were made by Honeywell (HIH-3602-C) and consist of a thin film platinum resistance temperature detector (RTD) and a thermoset polymer capacitive RH sensor. The temperature/RH sensors were mounted in aspirated radiation shelters and were cross calibrated before and after the field campaign.

	RH	RTD
R^2	.99994	.99996

Chart 1: Mean R^2 for RH and temperature sensors.

Mean change in linear calibrations:	RH	RTD
Slope	0.0002	0.003
Offset	.5%RH	0.07°C

Chart 2: Mean absolute values of the change in slope and offset between pre-experiment and post-experiment calibrations.

The change in calibration between pre and post-experiment calibrations are the same order of magnitude as the smallest observed gradients in temperature and RH within the canopy, and they are 2%-3% of the larger observed gradients.

2.3 Data Quality

The experiment was designed to test a two dimensional higher-order closure model. This model simulates the turbulent transport of a scalar in air entering the canopy perpendicular to its edge. Duplicating this with the highest special resolution feasible, in our experimental design we allocated all of our limited instrumentation along a north-south transect aligned with the predominant wind direction. The data presented here are for times when the wind direction was within 10 degrees of due south.

3. RESULTS

The experimental design and the suite of sensors used in the experiment succeeded in measuring significant changes in wind speed and scalar concentrations across the edge of the canopy. Measured horizontal advection is large near the edge – often greatly exceeding the magnitude of vertical fluxes. The measured scalar profiles and turbulence data confirm key features predicted by the high order closure model near the edge.

3.1 Experimental Results

In figures (1) and (2) measured vapor pressure and temperature values averaged from several days of data are presented by location in the field. The effects of the change in surface are apparent, as evapotranspiration from the irrigated crop adds moisture and lowers the temperature of the air after it enters the canopy.

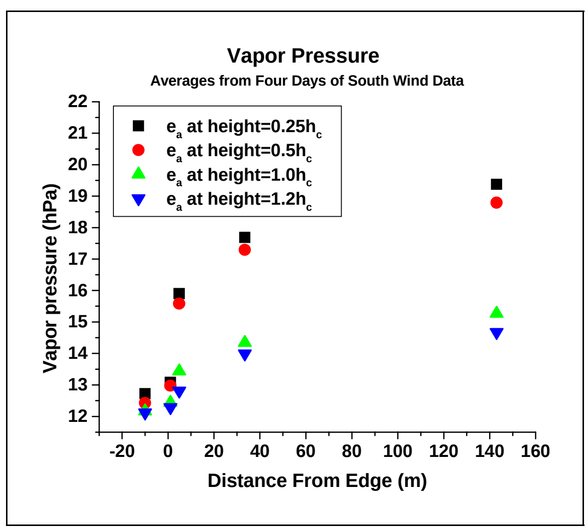

Figure 1: Vapor pressure averages by distance into the canopy.

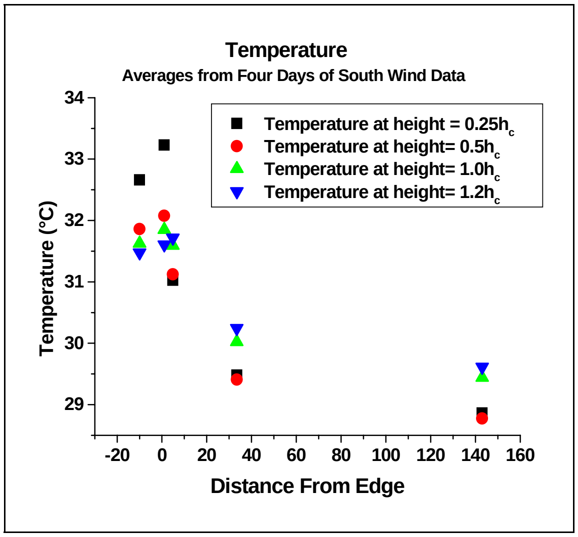

Figure 2 Temperature averages by distance into the canopy.

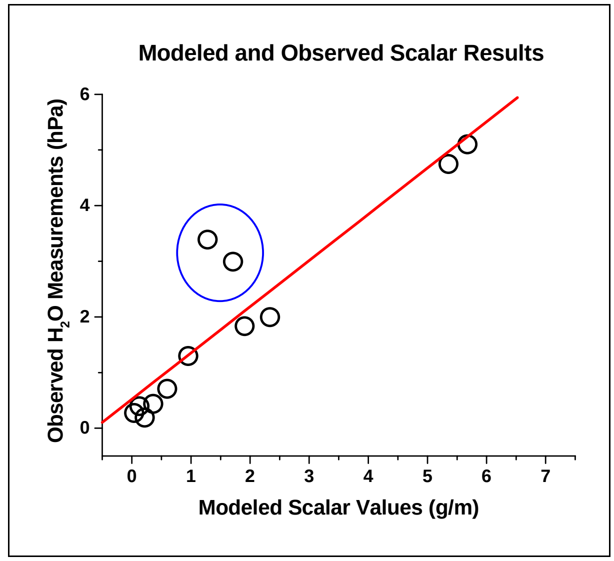

Figure 3: Scalar concentrations output by the model vs. change in observed water vapor.

The temperature data reveals some features which the model cannot currently reproduce. Initially temperature rises when air enters the canopy. This may be due to the fact that vertical wind caused by pressure perturbations at the edge forces the warm air near the ground up, in effect lifting the strong gradient which exists outside of the canopy.

3.2 Comparisons Between Model Results and Experiment

In the figure (3) the output of the two dimensional higher-order closer model is compared with observed values at 3 different distances into the canopy and at four different heights. Ambient observed values upwind of the canopy are subtracted from the values measured in the canopy as the model contains zero scalar upwind of the canopy. The modeled scalar values match the measured values of water vapor with an R^2 value of 0.84.

The two circled values in figure (3) are from h = 0.25 h_c and 0.5 h_c at distance = 5 h_c into the canopy. These discrepancies may be due to the model predicting more momentum penetrating under the canopy near the edge than the sorghum permits with its fuller and more bottom heavy canopy. Increased transpiration of the sorghum canopy due to edge effects may also contribute to these results.

In figure 4 the observed wind speed averages and the model output of wind speed are graphed by location. The observations are all scaled by a factor of 1.16, forcing the wind speed at distance = -10 h_c and height = 1.2 h_c equal to the modeled value at the same location. Due to the limited availability of sonic anemometers only six points are available for comparison within the domain of the model.

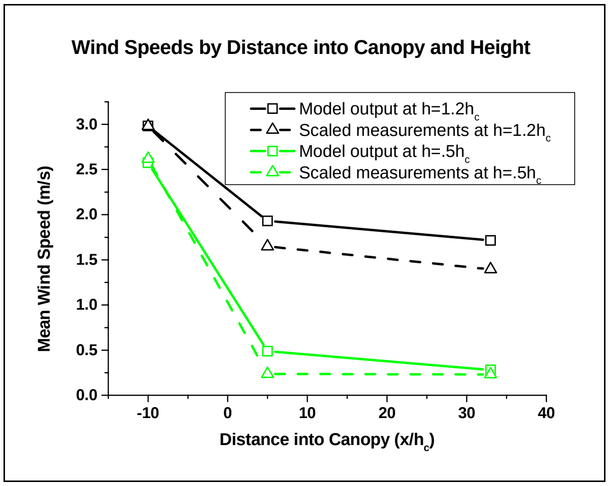

Figure 4: Modeled and observed wind speeds graphed by height and horizontal location.

In general the observations match the model results well, but the observed wind speed at x = 5 h_c and h = 0.5 h_c is half the magnitude of the modeled wind speed, suggesting that indeed differences in the wind speeds within the canopy could contribute to the discrepancies we see in the scalar measurements. The maximum LAI of the model is at 0.6 h_c, whereas the maximum LAI of the actual canopy is at 0.4 h_c. In addition the LAI of the sorghum is 4 during this time, while model results are for an LAI of 3. Future changes to the LAI of the modeled canopy may help resolve these inconsistencies.

In figure (5) the same wind speed observations scaled in figure (4) are regressed against the modeled wind speed results.

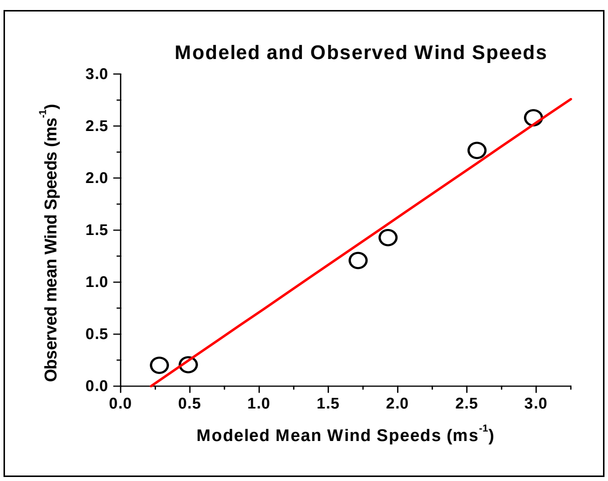

Figure 5: Modeled wind speed graphed against observed wind speed.

Observed wind speeds regress against model output of wind speeds with an R^2 of 0.98.

4. DISCUSSION

The carefully calibrated temperature/RH sensors worked well for this short intensive experiment. However two of these sensors began malfunctioning once they were exposed to high RH for extended periods of time at end of the post-experiment cross calibration. This sensor is well suited for this type of experiment, but cannot be used to replace more robust temperature/RH sensors designed for extended use in the field.

Field measurements of mean wind speed and scalar concentrations match the modeled measurements extremely well. Planned changes to the LAI profile of the canopy may further improve the correlation between the model and the observations.

The higher-order closer model distributes scalar source evenly over the leaf area. When the soil surface is dry, the measurement of water vapor release within the actual canopy reproduces this approximately. Temperature however deviates largely from this model in part because radiation transfers to and from the ground, making the ground a heat sink or source in addition to the plants. This problem we limit to some extent by restricting our direct comparisons with the model to times when the canopy is at its fullest, but it cannot be eliminated entirely without altering the source/sink distribution in the model. In addition, upwind of the modeled canopy there is no source of scalar, but in the field experiment we often have a large source or sink of heat from the ground upwind of the canopy. One proposed solution to this discrepancy is to add a profile or a source of the modeled scalar upwind of the canopy. We would then allow the modeled turbulence to act on the scalar profile and possibly reproduce the field observations near the edge of the canopy.

Because the model does not include diabatic effects, one additional potential source of discrepancy is the existence of varying stability regimes. Future analysis including comparisons between the neutrally stable model results and the field results under varying stabilities will help show the magnitude of the effect of stability on the observations.

5. ACKNOWLEDGEMENTS

This research was funded by the California Bay-Delta Authority through the Cosumnes Research Group. This research was also made possible by funding from the Kearny Soil Science Foundation and the Western Regional Center (WESTGEC) of the National Institute for Global Environmental Change (NIGEC) through the U.S. Department of Energy (Cooperative Agreement No. DE-FC03-90ER61010). Any opinions, findings and conclusions or recommendations expressed herein are those of the authors and do not necessarily reflect the view of the DOE.

6. REFERENCES

Baldocchi, D.D., 2003. Assessing the eddy covariance technique for evaluating carbon dioxide exchange rates of ecosystems: past, present and future. Global Change Biol. 9, 479–492.

Park, Y.-S. 2006. Numerical Study of Scalar Advection in Canopies Using a Higher-order Closure Model. Ph.D. Dissertation Univ. of Ca. Davis.

Paw, U.K.T., Baldocchi, D.D., Meyers, T.P., Wilson, K.B., 2000. Correction of eddy-covariance measurements incorporating both advective effects and density fluxes. Bound-Layer Meteorol. 97, 487–511.